



# Dry-mass conservation and water consistency in reanalysis

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# Outline

- ☐ Introduction & Motivation
- ☐ Changes in Atmospheric DAS
- ☐ Evaluation in Pre-MERRA-2
- ☐ Preliminary Results from MERRA-2
- ☐ Closing Remarks



# Introductory Remarks

- ❑ Latest reanalyses are still impacted by changes in observing system (e.g., Bosilovich and Robertson 2011).
- ❑ Additionally, Trenberth and Smith (2005) suggest the globally-integrated dry mass of the atmosphere should be conserved to first order in reanalyses\*.

\*ignoring fossil fuel burning, loss to space, anthropogenic effects, and outgassing in volcanoes.



# Motivation

## Evaporation & Precipitation

MERRA  
ERA-Interim  
JRA-55  
NCEP-CFSR

- Imbalances in E & P might not be physical
- P changes volatile wrt E
- P changes seem more affected by changes in Observing System

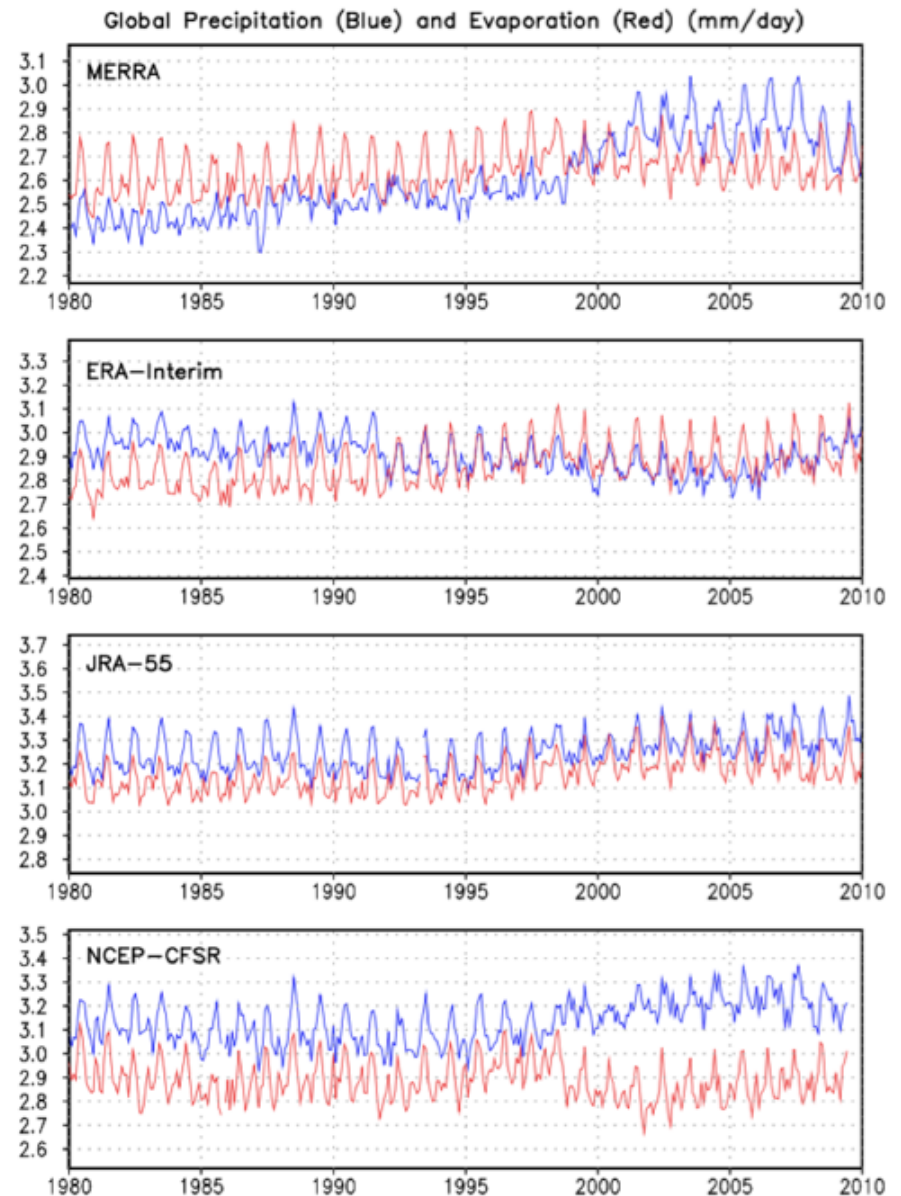


Figure: monthly mean globally-integrated P & E



# Motivation

In this work, total mass is simply the sum of atmospheric dry mass and the mass of total water content, i.e.

$$p = p_d + p_w$$

in units of hydrostatic pressure.

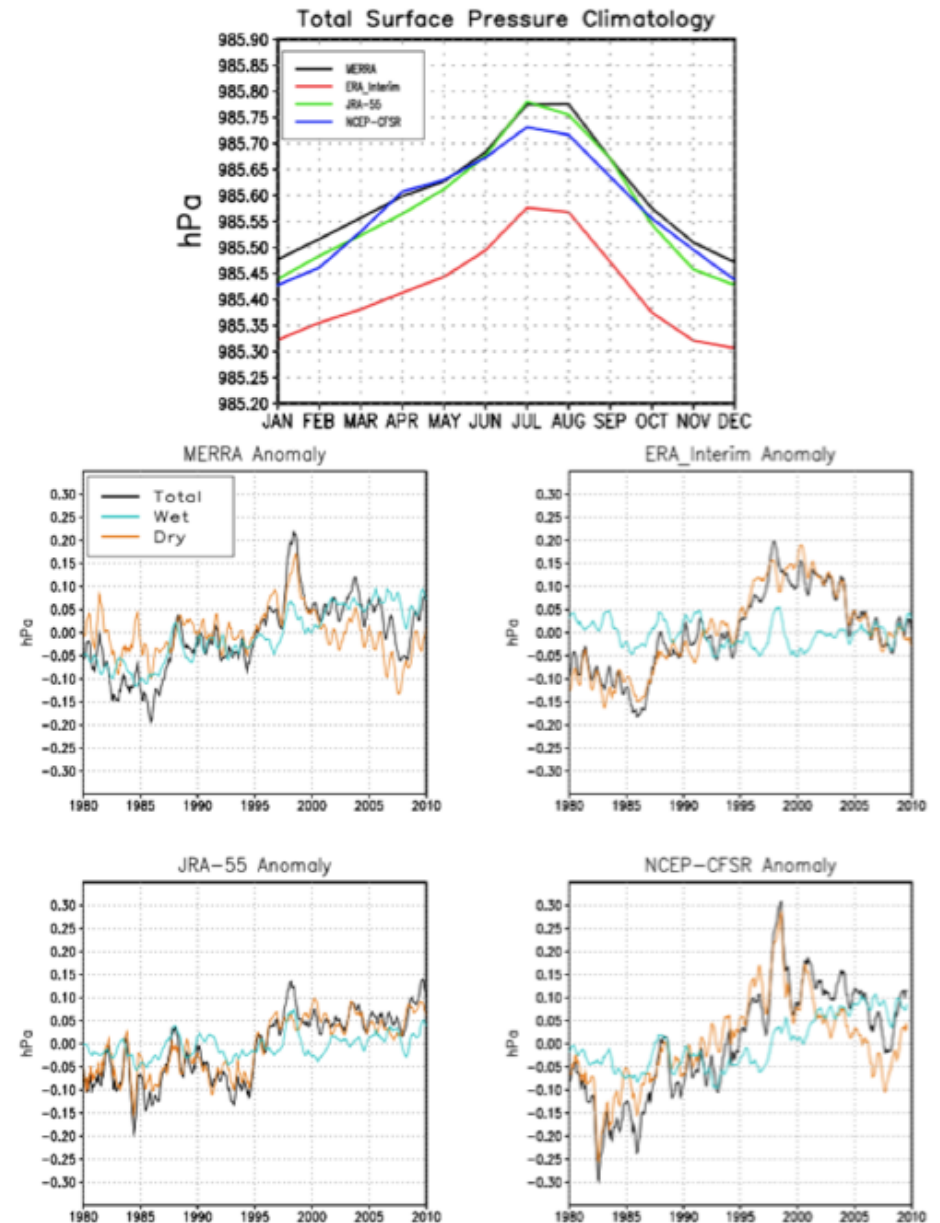
$$p = \int_{p_s}^{p_t} dp ,$$

$$p_w = \int_{p_s}^{p_t} q_w dp ,$$

with

$$q_w = q_v + q_l + q_i ,$$

Figure: Climatology and monthly mean anomalies of globally-integrated mass for four reanalyses; split into dry and wet.





# Changes to Atmospheric DAS

In GEOS ADAS ...

conservation of dry-mass is achieved by implementing:

- ☐ Adjustments to the model internal handling of surface pressure and water variables so that changes in total mass are purely driven by changes in total water (due to moist physics). Done in a way as to preserve constant constituent mixing ratio with respect to dry air when applicable.
- ☐ Constraint to the analysis system to better preserve the total dry mass: no increment in total dry mass.
- ☐ Adjustment to surface pressure and water tendencies of IAU to compensate for the fact that in principle these tendencies would be constant within the 6-hour assimilation window.



# Setting up the Atmospheric GEOS GCM

Setting a value for  
MERRA-2  
dry mass:  
983.24 hPa

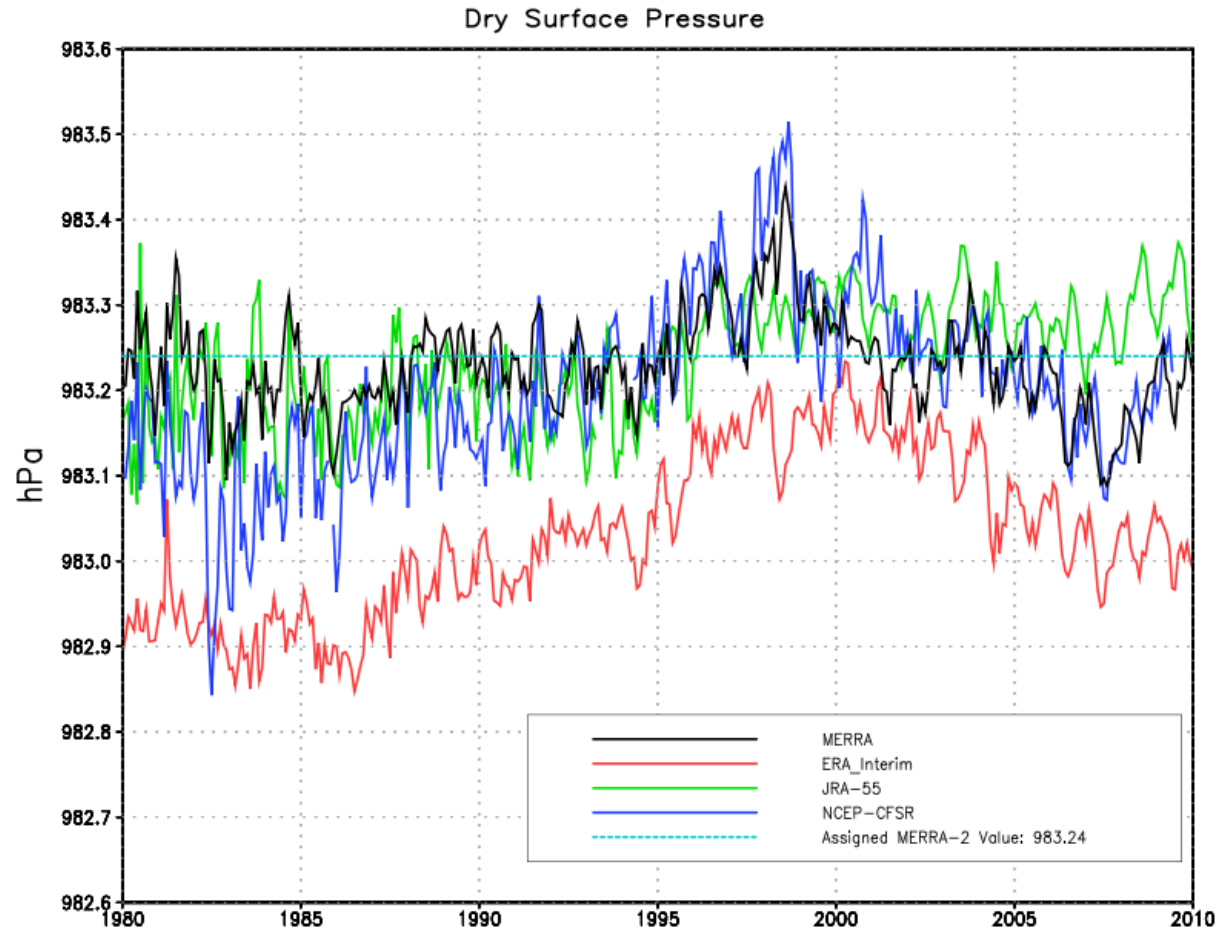


Figure: Globally-integrated dry surface pressure from four reanalyses; and value set for M2

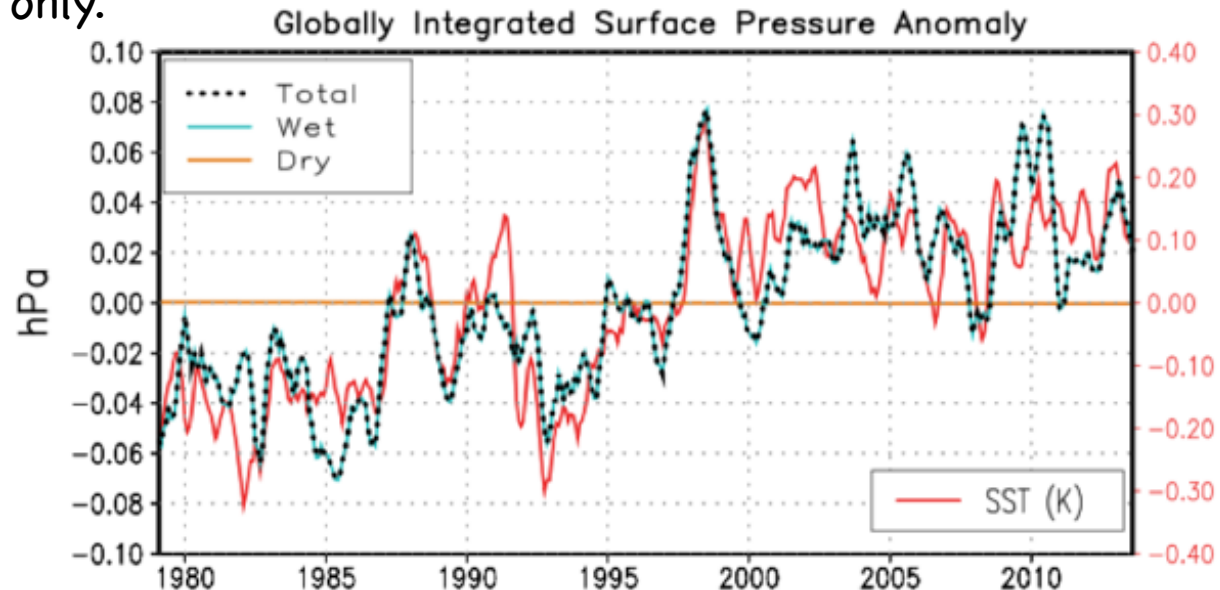
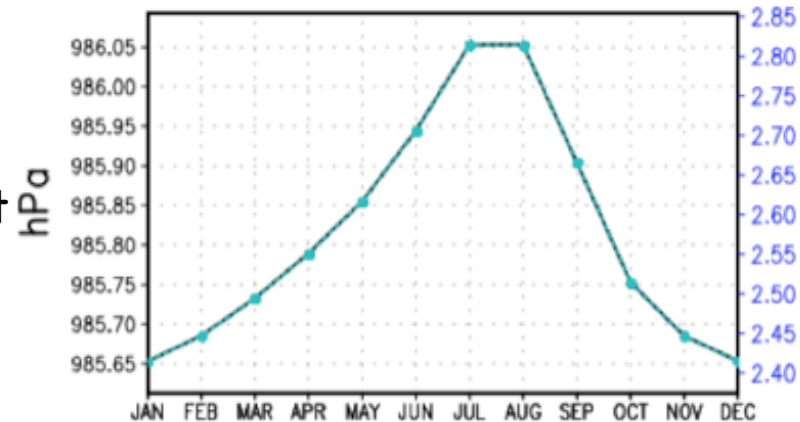


# Atmospheric GEOS GCM AMIP

The adjustments to the Atmospheric GCM leave:

- Dry mass unchanged throughout an AMIP experiment
- Changes in globally integrated mass fully correlating to changes in the wet component only.

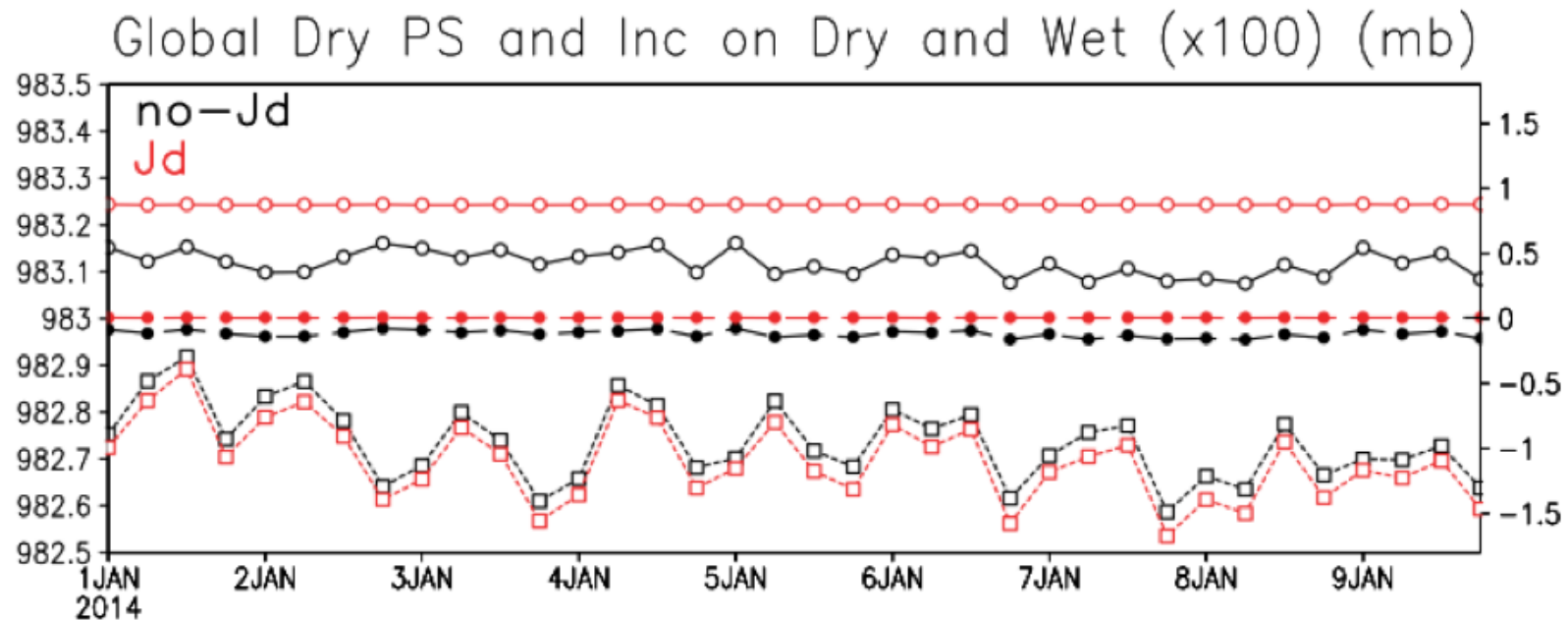
Total (Black) and Wet (Blue) Surface Pressure Climatology







# Atmospheric GEOS GSI Analysis



A constrained GSI analysis essentially leaves incremental changes to the total dry mass alone; assimilation of observations can only induce changes in total wet-mass.



# Evaluation in Pre-MERRA-2

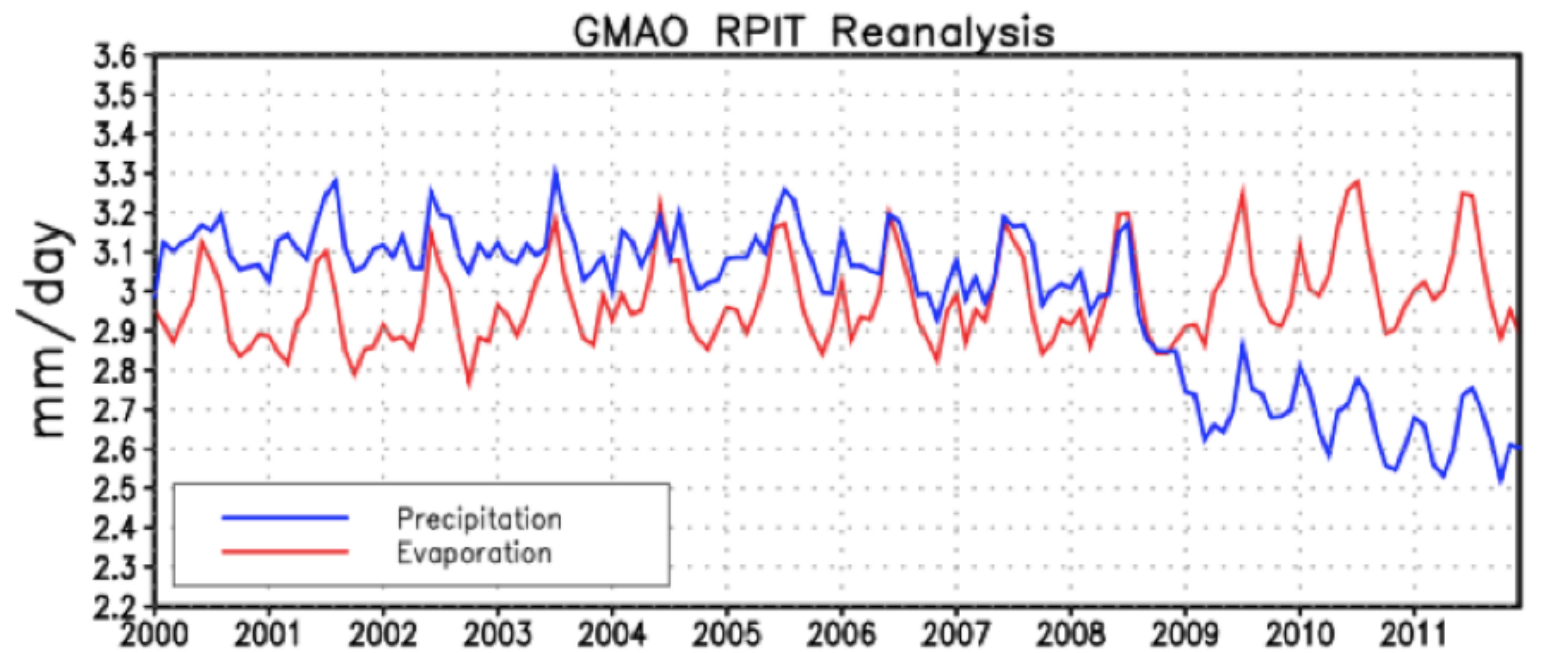


Figure: Monthly mean globally-integrated P & E from Pre-MERRA-2 experiment (RPIT).

Two test experiments (re-runs for RPIT March 2003 & 2009):

- ❑ **ADAS-1**: Modifies AGCM & GSI, but leaves IAU untouched
- ❑ **ADAS-2**: All changes applied to ADAS.



# Evaluation in Pre-MERRA-2

In Pre-MERRA-2:

Variations in total surface pressure are not in sync with its wet component.

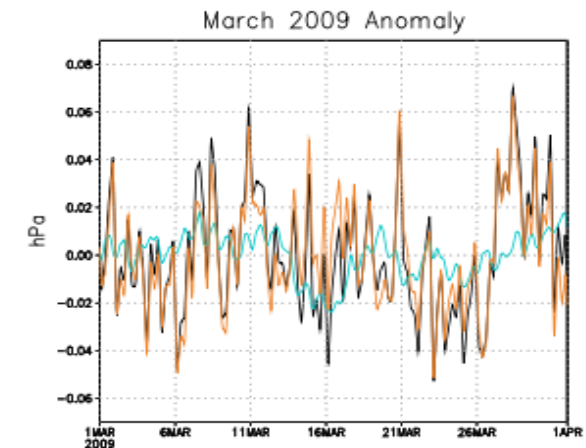
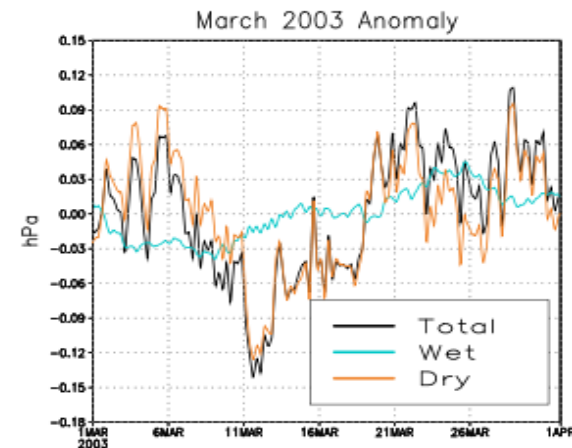
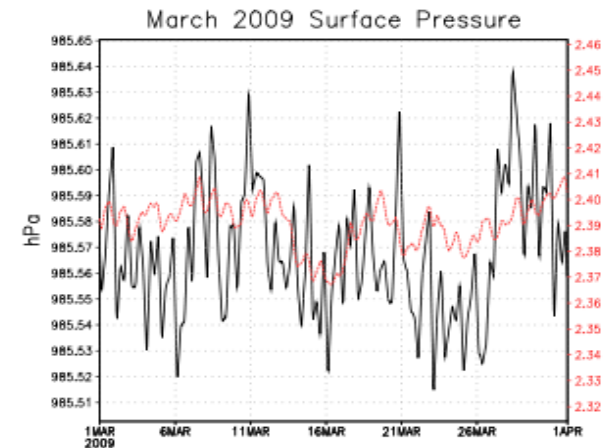
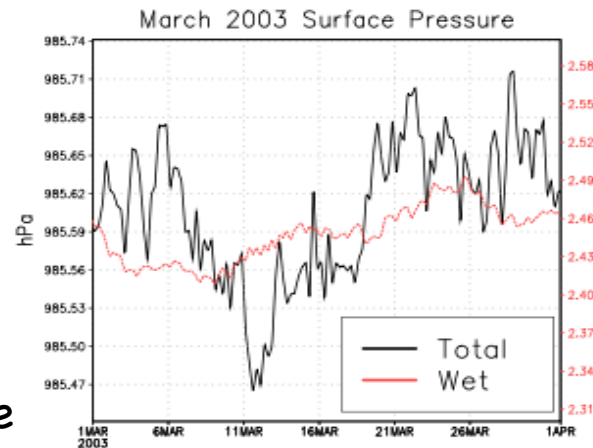


Figure: Globally-integrated surface pressure and its wet and dry partition from Pre-MERRA-2 experiment (RPIT), for March 2003 and March 2009.



# Evaluation in Pre-MERRA-2

When GCM and GSI are adjusted to preserve dry-mass there is considerably more consistency between total mass and corresponding wet component.

But dry-mass still not fully conserved ...

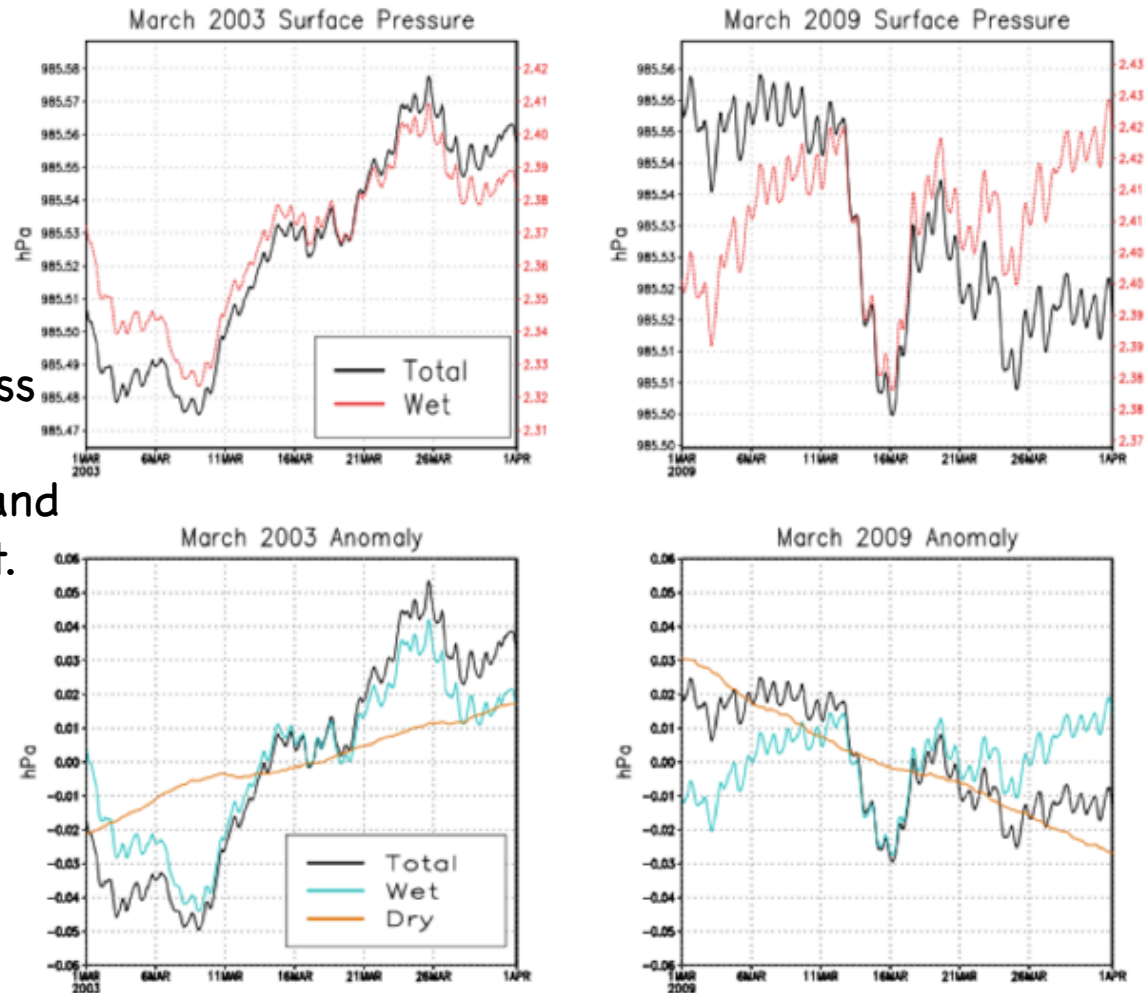


Figure: Monthly mean globally-integrated P & E from Pre-MERRA-2 **ADAS-1** rerun of RPIT.



# Evaluation in Pre-MERRA-2

When, additionally, the model is further adjusted to be consistent with a constant analysis increment over the course of the 6-hour assimilation cycle – by adjusting surface pressure and moisture tendencies at each time-step – conservation of dry mass is achieved in assimilation mode.

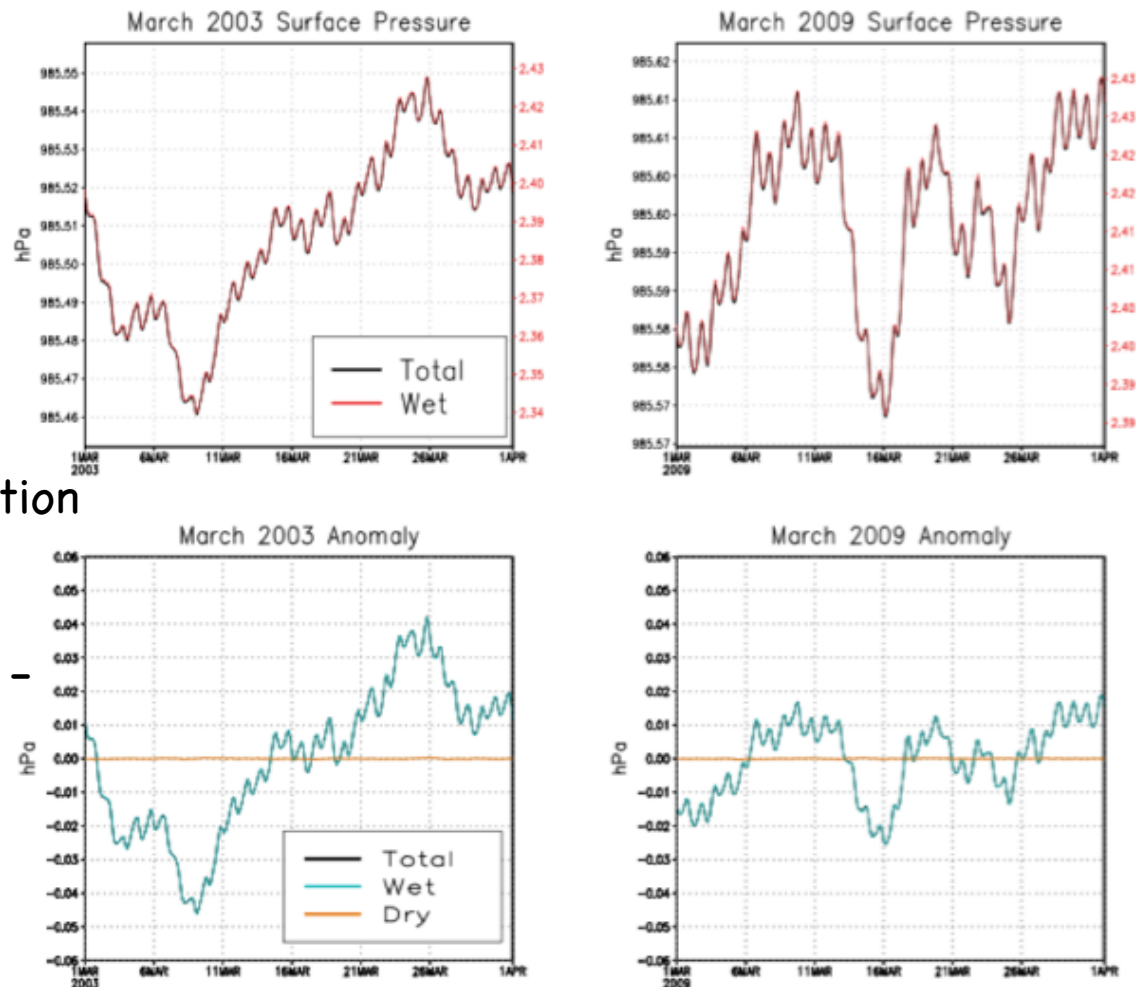
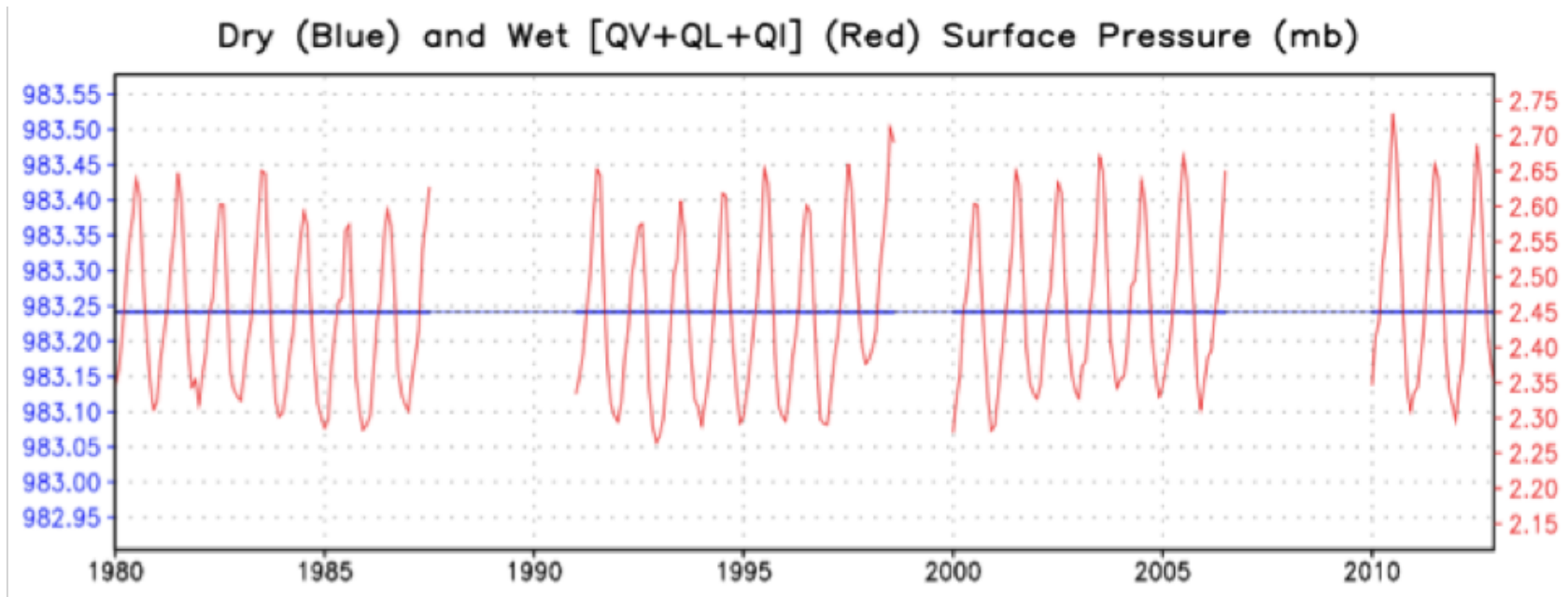


Figure: Monthly mean globally-integrated P & E from Pre-MERRA-2 **ADAS-2** rerun of RPIT.



# Preliminary Results in MERRA-2



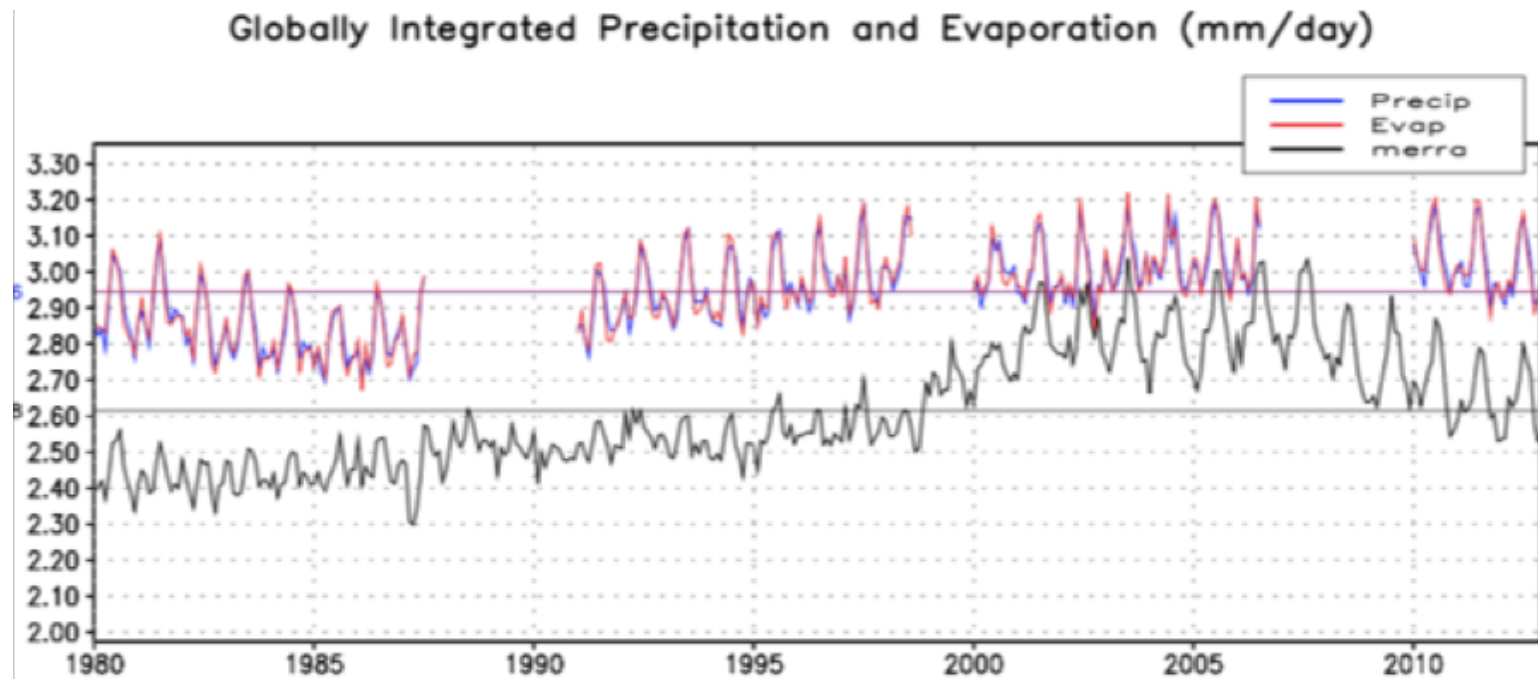
Preliminary look at MERRA-2 shows it to conserve dry-mass.

Figure: Globally-integrated surface pressure split into Dry and Wet portions (MERRA-2).





# Preliminary Results in MERRA-2



Global surface evaporation in MERRA-2 is in sync with precipitation and this latter shows less abrupt changes than MERRA which are largely induced by changes in the observing system.

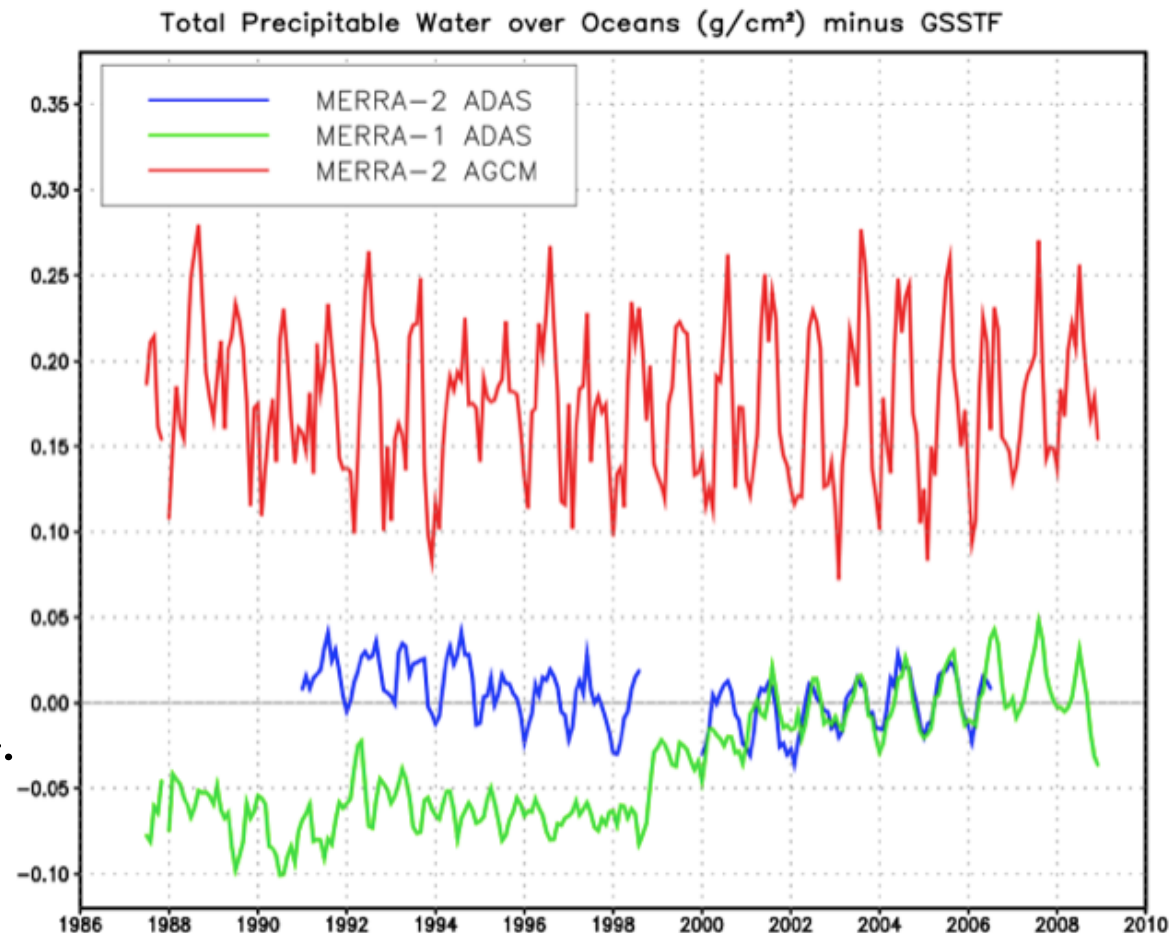
Figure: Globally-integrated P & E from MERRA-2 and comparison with MERRA.



# Preliminary Results in MERRA-2

Total Precipitable Water compared with GSSTF.

MERRA-2 diffs to observations are considerably smaller than those for MERRA.



GSSTF: Goddard Satellite-based Surface Turbulent Fluxes project; Shie et al. (2009)





# Closing Remarks

Conservation of Dry-Mass in MERRA-2 is achieved by implementing:

- ☐ Adjustments to the model internal handling of surface pressure and water variables so that changes in total mass are purely driven by changes in total water.
- ☐ Constraint to the analysis system to better preserve the total dry mass.
- ☐ Adjustment to surface pressure and water tendencies of IAU to compensate for the fact that in principle these tendencies would be constant within the 6-hour assimilation window.